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MEETING SUMMARY

ENERGY AND WATER CONSIDERATIONS FOR THE SUSTAINABLE REUSE AND RECYCLING OF MATERIALS

Roundtable on Science and Technology for Sustainability
Science and Technology for Sustainability Program

Board on Energy and Environmental Systems
Water Science and Technology Board
September 10, 2013

On September 10, 2013, the National Research Council's Science and Technology for Sustainability Program, in collaboration with the Division on Engineering and Physical Sciences' Board on Energy and Environmental Systems and the Division on Earth and Life Studies' Water Science and Technology Board, convened a meeting of research leaders and technical experts in private industry as well as representatives from government and academia to examine the energy-water considerations of material reuse and recycling. The meeting examined the data and research needs for assessing the energy-water linkages with the reuse and recycling of waste streams and materials; the technologies and approaches needed to further recycling and reuse strategies, including design considerations for new and emerging products; and how the public and private sectors can leverage the efforts of key stakeholders to further technological development, innovation, data collection, and research to move sustainability strategies forward in the reuse and recycling of waste streams and materials.

Current and emerging technologies are dependent on a limited number of materials, such as rare earth and transition metals, which are derived from finite resources. Extensive use of these resources can pose challenges to societies for maintaining and improving their standard of living.

The supply and availability of natural resources will depend, in part, on overcoming technical challenges as industry and federal research strive to develop new technologies to minimize or reuse resources. In considering the recovery and recycling of materials, it will become increasingly critical that companies consider the energy and water implications.

Carl Shapiro, senior economist, Energy and Minerals, and Environmental Health, and director, Science and Decisions Center at the USGS chaired the meeting and asked participants to consider several overarching questions:

- How can we take a systems approach to waste, water, recycling, and reuse issues and make integrated assessments that inform policy decisions that impact our future economic, environmental, and social well-being?
- How can we use a systems approach to assess the economic, environmental, and social trade-offs in making those decisions?
- What is the role of research in moving forward with making these decisions?
- What are the appropriate roles of the private and public sectors in these efforts?

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In response, there were several overarching themes that participants discussed through the course of the meeting:

- Data availability across the energy, water, and waste domains is not equal, making comparisons and life-cycle assessments challenging. Data for water consumption and water withdrawals relating to energy production inputs are available and well understood. There are extensive records on energy sources, flows of energy, and electric generating units. The energy-water linkage is well characterized; however, waste is not. Solid waste generation data are generally collected by municipalities, but not at the federal level.
- Closing energy, water, and waste loops in industrial facilities can be challenging, because these facilities are older structures that are inherently inefficient by design. The up-front capital costs for upgrading this infrastructure in optimizing systems to capture energy, water, and waste streams can often be cost prohibitive for many industries.
- Municipalities and industries will continue to replace old infrastructure where and when they have funding to do so, but it is important to move ahead of these issues with strategic planning or by using a framework for analysis in order to better inform decision makers and to optimize spending on capital costs.
- The cost of water was raised as an issue that needs to be addressed in order to better price trade-offs between domains—like water, energy, and waste. Water rights present another a challenge, and affect the ability to price water accurately.
- Designing products for recycling was also discussed by participants as another approach in addressing the reuse of materials. A major challenge is that manufacturers design products for performance instead of for end-of-life uses and recycling.
- There is tremendous potential for research on energy, water, and waste linkages that could benefit from public-private partnerships. Participants discussed the economic benefit of these partnerships in that they can address ongoing challenges, such as taking account of externalities and moving technology through the “valley of death” that most new technologies encounter. Partnerships can bridge the gap between applied research and mature technologies the private sector values.

The Energy-Water-Waste Nexus: A Systems Approach

David LoPiccolo, director of Integrated Water and Energy Sustainability Platform for Siemens Industry, Inc., described the goal of his team as helping industry identify ways to improve energy use and decrease water use. Mr. LoPiccolo’s approach is to help executives understand how to assess facilities as a holistic system, identify all the water and energy inputs, and provide them with a plan of action. Since the energy crisis of the 1970s, facilities have assessed their operations thoroughly, so the data needed to evaluate them holistically are already collected. Executives are not always aware of these data and are under tremendous pressure to make decisions; however, wrong choices could bring unwanted risks. There are often decisions made to make either an environmental improvement or an operational improvement. These divergent drivers slow progress in facilities, because there is a lot of information but unclear paths forward. It is important to take a holistic approach—starting with an awareness step to fully understand how a facility operates within the water and energy sustainability space. A deeper dive into a facility’s operation is necessary to identify every water stream, energy source and sink, and associated wastes. Once this is done across the whole facility, the potential cost savings for changing water and energy use become clear.

Mr. LoPiccolo stated that most of an industry’s freshwater intake has energy added to it in some form, such as heating—water and energy are no longer considered independently. He provided an example of how systems are interrelated by describing a major food manufacturer, which had a large, inefficient steam system. The manufacture was using an older, chemically intensive pretreatment and needed to optimize the system. A thorough analysis resulted in using output from the existing water system to accomplish cooling needs, capturing that energy, and then using that captured energy for the boiler system, resulting in less primary water and energy use for the boiler. Multiple water streams were reduced and energy was captured from the system, resulting in water, energy, and cost savings.

Fiber recovery in paper mills was given as another example. The waste stream from a paper mill contains residual fibers, and facilities can capture that fiber and reprocess it into the head box of paper machines for more product made per ton raw material used and less waste generated. An added benefit is that capturing those fibers is also a water-recycling strategy, since this would be the first step in treating that water for reuse. A third example discussed by participants was capturing biogas from a facility’s wastewater treatment to produce energy for the facility.[1] Once the wastewater passes through this treatment process and the biogas is captured, most of the treatment necessary for water recycling is accomplished. Instead of discharging that water as effluent, it can be reused in the facility as gray water for nonpotable uses. One ongoing challenge underlying these three examples is that most of the industrial facilities in the United States are older structures and are inherently inefficient. The up-front capital costs for upgrading this infrastructure in optimizing systems to capture energy, water, and waste streams can often be cost prohibitive for many industries.

The Energy-Water-Waste Nexus: Critical Metals

Mark Caffarey, executive vice president for Umicore USA Inc., discussed energy, water, and waste linkages related to the reuse of critical metals. Mr. Caffarey described criticality as being defined by the use of a given element. Rhodium, for example, is a critical element, because without recycling of the catalyst, there would not be enough rhodium for use in manufacturing. The Department of Energy has defined criticality, and focuses on critical elements needed for energy in the United States.[2] Umicore processes over 300,000 tons of secondary materials each year, specializing in collecting electronics, catalytic converters, and industrial catalysts at the end stages of life cycles to recover precious metals. The recovery process captures 18 elements, including platinum, palladium, rhodium, gold, silver, selenium, tellurium, arsenic, and antimony. Umicore estimates that by not mining raw materials, the recovery process prevents 1 million tons of carbon dioxide emissions per year.

Umicore conducted a life-cycle assessment study on their battery-recycling program and determined that recycling nickel and metal hydride batteries results in energy and water savings. There were also large savings in recycling lithium ion batteries, copper, and nickel. Nickel, for example, only requires a third of the energy for recycling that is needed for primary production. A challenge Umicore faces, as do other researchers, is confidence in the quality of data used in life-cycle assessments and in validating that data. Different commercial products have emerged to address this issue. For example, GaBi is a commercial software life-cycle assessment database, which is unique in that it is updated by software and databases developers – it is considered one of the most complete and robust software packages.

Participants discussed energy, water, and waste challenges in addressing reuse and recycling. The cost of water was raised as an issue that needs to be addressed in order to better price trade-offs between domains—like water, energy, and waste. Water rights present another challenge, and affect the ability to price water accurately. Water, waste, and energy are all regulated differently, presenting challenges in understanding how to make trade-offs among different domains. Accurate pricing of water and energy will be necessary to optimize trade-offs in the future. Another challenge to recycling water is the negative perception of recycled water for use in food and beverage facilities or with gray water use from treatment plants in the western United States.

John Bissell, chief executive officer and cofounder of Micromidas, Inc., discussed California's challenges addressing water needs and infrastructure. Although, there have been efforts to change end-user behavior to increase water supply and availability, the larger, more challenging infrastructural improvements have not yet been addressed. There is a sense of urgency with this issue, because of the time frame that would be required to respond to a significant drop in water availability. Mr. Bissell added that there is value in prioritizing the infrastructure needs for improving water capacity and availability while also improving efficiency, which could be improved quickly in a time of significant loss in water availability, such as with drought.

Current regulatory statutes can also be a challenge to innovative solutions in the reuse of water or waste. William Cooper, program director of the Environmental Engineering Program, Division of Chemical, Bioengineering, Environmental, and Transport Systems at the National Science Foundation, commented that wastewater treatment plants are regulated to meet the Clean Water Act, which was established in the 1970s. The design of the treatment plants has not changed significantly since the Clean Water Act was established. It can be challenging to find flexibility to use innovative technology under a command-and-control regulatory framework.

Complex Supply-chain and Life-cycle Assessments

Evaluating complex supply chains and performing life-cycle assessments on products are key approaches researchers in the private sector, federal agencies, and academia are using to better understand the flow and economics of a wide array of materials. Adam Carroll, project manager and

[1] Biogas refers to a gas produced by the breakdown of organic matter in the absence of oxygen, and is composed of up to 50% to 80% methane and 20% to 50% carbon dioxide.

[2] See www.energy.gov/pi/office-policy-and-international-affairs/initiatives/department-energy-s-critical-materials.

principal investigator for Oak Ridge National Laboratory's Strategic Materials Security Program, discussed their approach to assessing supply chains for the Defense Logistics Agency (DLA). The Strategic Materials Analysis and Reporting Typography (SMART) program allows the DLA to ensure the materials necessary to reconstitute defense platforms lost during an emergency are available to rebuild essential infrastructure, such as power plants. The SMART program compiles data from a wide range of sources to build out the supply chain of hundreds of materials considered essential by the DLA.

Data evaluation is a key step in the process to ensure accuracy. Evaluating entire supply chains helps identify risks where the supply for a given material may be limited. Supply chains for materials can become very complex. Arsenic, for example, is only mined in three other foreign countries as arsenic trioxide. It is then processed into a metal or acid form before entering the United States where it is incorporated into batteries, night vision systems, and wood treatment. Once arsenic is tracked from a mine through all these product supply chains, the system can be analyzed to identify where risk in supply exists and where alternative actions can be taken to address those risks.

Matthew Eckelman, assistant professor of civil and environmental engineering at Northeastern University, described how life-cycle assessment is used to assess different points in the energy, water, and waste nexus. Life-cycle assessment is a systems modeling tool, and is used to holistically evaluate all resource inputs into a given product or process. It is a flexible tool that allows for analysis at multiple scales—from the molecular level to city blocks. One key area of research in life-cycle assessment is at analyzing the benefits of materials reuse and recycling, and to examine linkages across different resource domains.

Data availability across the energy, water, and waste domains is not equal, making comparisons and life-cycle assessments challenging. Data for water consumption and water withdrawals relating to energy production inputs are available and well understood. There are extensive records on energy sources, flows of energy, and electric generating units. Datasets are improving for understanding water effluent from power generation facilities. The energy-water linkage is well characterized; however, waste from power generation facilities is not. Solid waste generation data are generally collected by municipalities, but not at the federal level. The U.S. Environmental Protection Agency (EPA) does not measure municipal solid waste (MSW) generation in the United States, but rather estimates it using a material flow model. Data from empirical measurements of waste generation does not exist to the same extent as energy and water data.

There are tremendous benefits in reusing nonhazardous industrial waste. Dr. Eckelman performed a life-cycle assessment on the benefits of waste reuse in the state of Pennsylvania, which requires reporting of waste generation, recycling, and reuse, resulting in a robust dataset of how much waste was reused across the state. The life-cycle assessment tracked energy benefits of reusing materials, assuming they were substituted for primary materials, and demonstrated that on an energy-equivalent basis, the benefit was larger than Pennsylvania's annual production of renewable energy (Figure 1).

Dr. Eckelman also reviewed the energy, water, and waste life-cycle implications at the Campbell Industrial Park in Oahu, Hawaii. The industrial park consists of a power plant, two oil refineries, and other industrial companies that interact in an industrial symbiosis—they share materials, water, and energy. For example, two oil refineries share steam, one sells sludge to an energy company, and a scrap tire shredder supplies alternate fuel to the power plant. The life-cycle assessment demonstrated that the current reuse and recycling of materials at this industrial park comprised a large percentage of the energy needed for Hawaii's clean energy initiative policy goal, which states that 70% of the energy used on the island should be from clean energy sources.[3]

Private-sector Efforts to Further Technological Development, Innovation, and Research

Neil Hawkins, vice president of sustainability and environment, health, & and safety for the Dow Chemical Company, discussed private-sector efforts for furthering technological development, innovation, and research for addressing energy, water, and waste linkages. To scale up sustainability initiatives in the private sector, they will need to be profitable. Demonstration projects work well for research and development, but scalability needs profitability. The Dow Chemical Company, for example, completed its first set of 10-year goals that have made the business case for implementing sustainability into their processes and products. Solid waste was reduced by 1.6 billion pounds, water use was reduced by 183 billion pounds, and 900 trillion BTUs of energy were saved.

[3] Eckelman, M., and M. Chertow. 2013. Life Cycle Energy and Environmental Benefits of a U.S. Industrial Symbiosis. *International Journal of Life Cycle Assessment*, 18, 1524-1532.

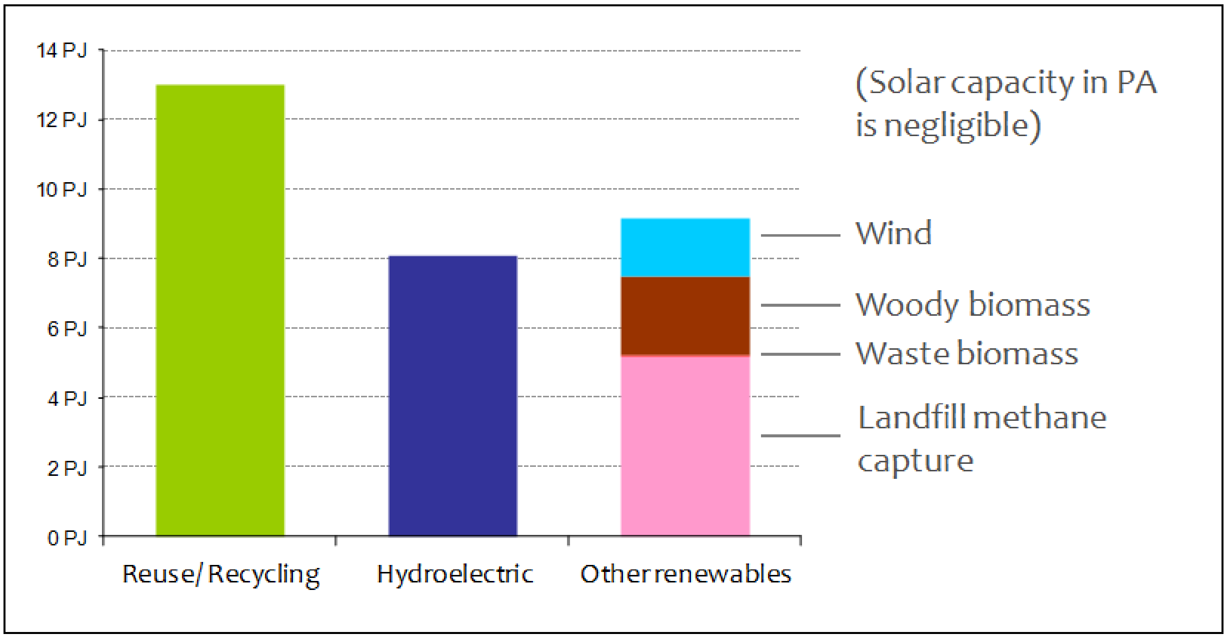

Figure 1 Life-cycle assessment results tracking energy benefits of reusing materials compared to renewable energy.
Source: Matthew Eckelman, Northeastern University, Presentation September 10, 2013.

These metrics translate into waste savings that could fill 415 football fields 1 meter deep, water savings that could serve 170,000 homes for a year, and energy savings that could power 8 million single-family homes for a year. For the $1 billion invested in these efforts, it is estimate that $5 billion was saved. The largest barrier the Dow Chemical Company had 20 years ago when trying to meet their goals was a lack of metrics. It took approximately 3 years to build the metrics to support the goals that were set in the first 10 years. For the second 10 years, there are metrics and a culture of tracking and improving the measurements, but there is more constraint around capital that affects investment opportunities.

The private sector operates by a waste management hierarchy. First is to not make waste, if possible, which means better yield on the product and no waste management costs. Next is to reuse or recycle waste, then energy recovery from the waste, and finally, disposal is the last and least desirable option. Manufacturing companies also use Value Improving Practices, which are industry-shared best practices on how to improve productivity in design, including reduction of waste by considering changes in design upstream. These have proven to be successful, are voluntary, and are widely used among companies.

Reducing waste streams and reconsidering product design requires the right culture in a company and incentives so that those who push for these efforts are rewarded. Recycling and reuse, constraints that can inhibit a company from being able to recycle a given material. For example, reducing some pollutants, such as nitrogen oxides and sulfur oxides from emissions, are required by regulation but generally offer no economic benefit. Other compounds, such as aluminum, iron, and bulk enzymes are thermodynamically and economically favorable to recycle. Some metals, such as lead, silver, cobalt, and platinum fall on a recycling boundary and are only economical to recover if they are present in large-enough concentrations or if the market has driven up their value significantly.[4]

Public-sector Efforts to Further Technological Development, Innovation, and Research

Dr. Shapiro offered the USGS perspective on furthering research and development to better understand the linkages among the energy, water, and waste domains. USGS believes it is important to organize science and datasets in such a way that they move beyond a single metric and a single objective to be more useful to decision makers. In 2007, the USGS reorganized and created a new set of strategic goals that attempted to break out of its traditional discipline-related silos.

[4] Dahmus, J. B., and T. G. Gutowksi. 2007. What Gets Recycled: An Information Theory Based Model for Product Recycling. *Environ. Sci. Technol.*, 41, 7543-7550.

Resource management in the federal government needed to be addressed more broadly than along traditional academic disciplinary lines.

The USGS science strategy encompasses a life-cycle approach and has an interdisciplinary focus. As the synthesis and interpretation of data, information, predictions, and contextually based knowledge increases, the usefulness of the science to decision makers also increases. Merging current capabilities with emerging scientific areas, such as ecosystem services and sustainability, will be important in addressing the connections among resource assessments and broader societal issues. Decisions will need to be made about assessing multiple resources or multidisciplinary resources, such as the land use, water, biological, and economic considerations when extracting coal to meet energy demand.

Understanding the criticality of materials is a key example of assessing multiple resources. Criticality is a function of supply risk and importance of use—if there is a significant supply risk to an important material, then it becomes a critical material. Environmental sensitivity is now being considered into this definition as well. For example, if there is environmental sensitivity around the mining of a metal, then there is a potential regulatory issue or other geopolitical event that results in the supply of that metal being at risk, thus making it critical.

USGS is addressing how to better inform decision makers about which materials are most critical and developing better metrics as indicators for criticality. Integrated life-cycle assessment is a tool that has been used to look at traditional material flows and evaluating them for impacts and vulnerabilities (Figure 2).

Public-private partnerships were raised as an example of how to better address the research, innovation, and funding needs that would result in more informed decisions. Mr. Caffarey highlighted the Center for Reduction, Reuse and Recycling (CR^3), which is an industry-university collaborative, partially funded by the National Science Foundation, dedicated to the sustainable stewardship of resources. CR^3 serves the collaborative members' needs by establishing the needed knowledge base, educating leaders in industry, and developing technologies to be transferred to industry with the goal of achieving materials sustainability. Worcester Polytechnic, Colorado School of Mines, and the University of Leuven in Belgium are collaborators, and each has a charter to bring at least five private companies into the collaboration. Mr. Caffarey stated that although the regulators are not involved in the partnership, it is a positive example of the private sector and academia working together because the industries have a strong voice in what research projects will be pursued.

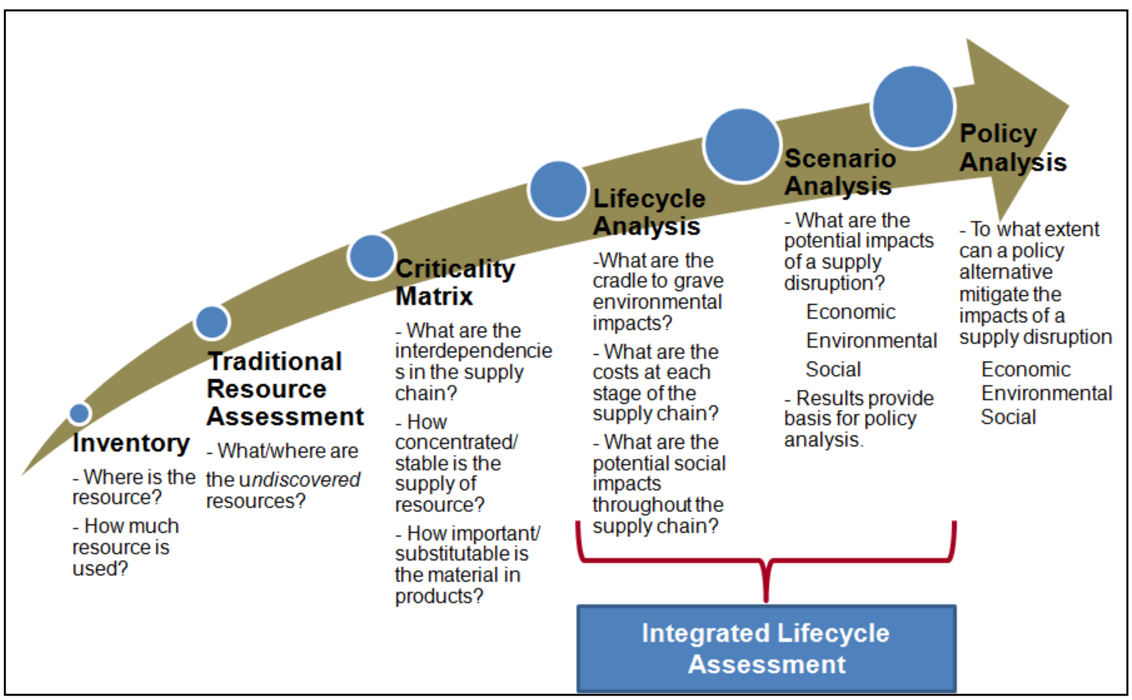

Figure 2 Integrated life-cycle assessment in assessing the use of natural resources. Source: Carl Shapiro, U.S. Geological Survey, Presentation September 10, 2013.

Although CR^3 has focused on the technical needs of recycling and resource use, there may be an opportunity for this collaboration to also address some of the overarching data validation needs for life-cycle assessments. Dr. Eckelman added that the U.S. Department of Agriculture (USDA) has also been very active in developing their LCA Digital Commons, which is a collection of open-access life-cycle assessment datasets and tools, which help make LCA data more accessible to the community of researchers, policy makers, industry process engineers, and LCA practitioners.[5] The data is peer reviewed by independent panels and hosted by the USDA, and it has been considered a model for development in terms of transparency and data review.

Dr. Cooper offered a different perspective on a public-private partnership. The Orange County Sanitation District spends roughly $20 million each year disposing of biosolids from wastewater treatment. Biosolids are regulated by the EPA as Class A or B, depending on the level of pathogens present in the material. There is an opportunity for a private company to partner with the treatment plant to develop and employ technology to convert Class B biosolids to Class A, a more pathogen-free designation, which would allow those biosolids to be sold as fertilizer to the public. This would save the public utility $20 million each year. There is an economic challenge in making the technology cost-effective and a public perception barrier; however, mining phosphate rock is limited and biosolids provide a renewable source of nutrients.

There is tremendous potential for research on energy, water, and waste linkages that could benefit from public-private partnerships. Dr. Shenoy described a public-private partnership DOE has with the Dow Chemical Company called the Manufacturing Demonstration Facility. The Dow Chemical Company is cost sharing a project on carbon fiber composites, because they see the value in partnering with an agency to help develop and mature a potentially profitable technology. Participants discussed the economic benefit of partnerships in that they can address ongoing challenges, such as taking account of externalities (e.g., climate change or water use) and moving technology through the “valley of death” that most new technologies encounter. The partnerships can bridge the gap between applied research and mature technologies that the private sector values for further developing. Participants also discussed the importance of including universities in these partnerships to incorporate the value academic researchers bring in developing methodologies and technologies.

Designing products for recycling was also discussed by participants as another approach in addressing the reuse of materials. A major challenge is that manufacturers design products for performance instead of for end-of-life uses and recycling. Incentives are needed to ensure design for recycling is considered up front. A successful example is the 1997 European Commission’s directive that aims at making vehicle dismantling and recycling more environmentally friendly, and sets quantified targets for the recycling and recovery of vehicles and their components. This legislation was officially adopted by the European Parliament and Council in 2000. Mr. Bissell commented that sometimes flexibility can be reduced when design requires an integration of multiple industries or components from different systems. Plastic industries, for example, are resistant to replacing polyethylene terephthalate (PET). There is a bio-based alternative, polyethylene furanoate (PEF), but it is being locked out by consumer product companies, because they are driven by the demands of consumers who want recycled content. If PEF is introduced into the recycling stream for PET, it will contaminate the recycling stream and reduce the amount of recycled PET available. There is an unintended consequence where the drive for recycling a waste product is inhibiting innovative development. There is a need to ensure that unintended consequences are avoided when considering water, energy, and waste linkages.

[5] See www.lcacommons.gov.

Participants: Craig Benson, University of Wisconsin; John Bissell, Micromidas; Mark Caffarey, Umicore USA Inc.; Adam Carroll, Oak Ridge National Laboratory; William Cooper, National Science Foundation; Matthew Eckelman, Northeastern University; Neil Hawkins, The Dow Chemical Company; David LoPiccolo, Siemens Industry, Inc.; Sarah Ruth, National Science Foundation; Carl Shapiro, U.S. Geological Survey; Devanand Shenoy, Department of Energy; Jessika Trancik, Massachusetts Institute of Technology.

Planning Committee: Carl Shapiro, U.S. Geological Survey (chair); Matthew Eckelman, Northeastern University; Bruce Hamilton, National Science Foundation. **NRC Staff:** Marina Moses, Director, Science and Technology for Sustainability Program (STS); James Zucchetto, Director, Board on Energy and Environmental Systems (BEES); Dominic Brose, Program Officer, STS; Dylan Richmond, Research Assistant, STS.

DISCLAIMER: This meeting summary has been prepared by Dominic Brose as a factual summary of what occurred at the meeting. The committee's role was limited to planning the meeting. The statements made are those of the author or individual meeting participants and do not necessarily represent the views of all meeting participants, the planning committee, STS, or the National Academies. The summary was reviewed in draft form by Mieke Campforts, Umicore and Anthony Ku, GE Global Research, to ensure that it meets institutional standards for quality and objectivity. The review comments and draft manuscript remain confidential to protect the integrity of the process.

About Science and Technology for Sustainability (STS) Program

The National Academies' Science and Technology for Sustainability Program (STS) in the division of Policy and Global Affairs was established to encourage the use of science and technology to achieve long-term sustainable development. The goal of the STS program is to contribute to sustainable improvements in human well-being by creating and strengthening the strategic connections between scientific research, technological development, and decision-making. The program concentrates on activities that are cross-cutting in nature and require expertise from multiple disciplines; important both in the United States and internationally; and effectively addressed via cooperation among multiple sectors, including academia, government, industry, and non-governmental organizations (NGOs).

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